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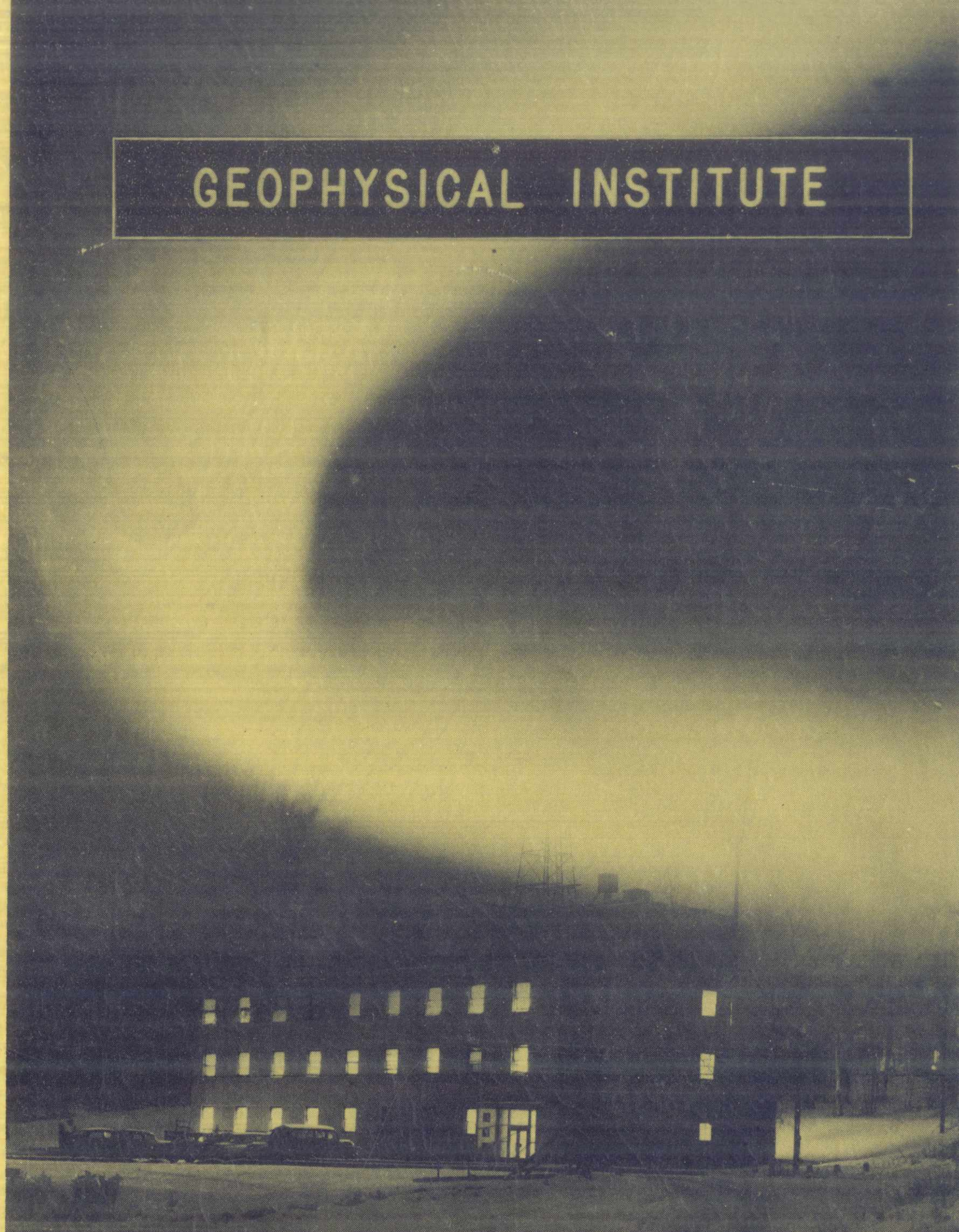

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Scientific Report No. 1

THE DETERMINATION OF THE LUNI-SOLAR VARIATIONS IN THE MAGNETIC ELEMENTS AT SITKA, ALASKA

1. PUNCHED CARD METHODS

AF 19(604) - 503

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THE DETERMINATION OF THE LUNI-SOLAR VARIATIONS IN THE MAGNETIC ELEMENTS AT SITKA, ALASKA

1. PUNCHED CARD METHODS

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ABSTRACT

The Chapman-Miller method of calculating harmonic coefficients for luni-solar daily variations is here applied to the hourly values of the magnetic elements at Sitka, Alaska for the period 1902-1952. The formation of the group sum sequences for groupings of the data according to solar activity, magnetic activity, lunar phase and lunar distance using punched card methods is described.

ERRATA SHEET

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Page	Line (s)	Correction
4	1, 2, 6, 7	In the expressions for Apr, Bpr, Apn and Bpn, the upper limit of the summation should read S-1 instead of S.
4	11	Delete 12 to read "sequences of numbers Nr,......"
5	6	(S = 24) for (S = 12)
5	Table I	Delete and replace by corrected Table. See below:

TABLE 12

Factors used in the reduction of L

$(-1)^{n-p}$ dmpS

n	p=1	2	3	4
1	.92561	.02971	.01047	.00548
2	-.13857	.95961	.04130	.01647
3	-.10087	-.10458	.97120	.04730
4	-.08862	-.06688	-.09298	.97721

D_{mpS}

n	p=1	2	3	4
1	1.07354	.14775-	0.12161	0.11904
2	-.03473	1.03129	0.10368	0.07730
3	-.01057	-.04697	1.01898	0.09278
4	-.00492	-.01594	-.05175+	1.01686

27		For 1936, should read 80 in the Annual Mean Sunspot Number Column
34		Delete 0,....1 under L in section (6).

SALT

Scientific Report I

1. Introduction

The purpose of this ionospheric-geomagnetic investigation is to determine the luni-solar tidal effects in the upper atmosphere at Sitka, Alaska, from the observations of the magnetic variations at the surface. The method employed is that developed by Chapman and Miller[1] and illustrated by Tschu[2,3]. This report describes the punched card methods necessary in the preliminary stages of the calculation.

The daily geomagnetic variations are of two kinds, solar and luni-solar. They provide information concerning the combined effects of the movements and conductivity - and therefore the ionization - of the ionosphere. This information is different from and supplementary to that provided by direct radio exploration methods. In particular, the combined effects shown by the daily magnetic variations depend on the large-scale general distribution of motion and ionization of the upper atmosphere whereas radio methods provide more direct but local information, mainly as yet concerning only the ionization.

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1. S. Chapman and J.C.P. Miller, "The Statistical Determination of Lunar Daily Variations in Geomagnetic and Meteorological Elements," Monthly Notices of R.A.S. Geophysical Supplement 4, 649-669 (1940).

2. K.K. Tschu, "On the Practical Determination of Lunar and Luni-solar Daily Variations in Certain Geophysical Data," Australian Journal of Scientific Research Research A, 2, 1-24 (1949).

3. S. Chapman, "The Calculation of the Probable Error of Determinations of Lunar Daily Harmonic Component Variations in Geophysical Data: A Correction," Australian Journal of Scientific Research A, 5, 218-222 (1952).

The lunar daily geomagnetic variation, though small, is worth much further investigation than it has yet received because in it a lunar tidal movement of the air of a known type acts in conjunction with the distribution of ionization governed by the sun. On the other hand in the solar daily variation the sun controls the heating and ionization as well as gravitational tidal effects so that the latter is less easily disentangled.

The lunar daily geomagnetic variation is so much smaller than the solar daily variation and the irregular effects of magnetic disturbance that it is necessary to use hourly or bihourly data extending over many years for its determination. This is particularly true when it is desirable to group the data according to several different factors, such as season, magnetic activity, sunspot activity, and lunar distance, to ascertain how they modify the variation.

Very little work has been done on the lunar tidal variation at stations of high geomagnetic latitude such as Sitka, College, or Point Barrow. This is due partly to the small number of observations at these latitudes, most of the stations only being set up for short periods as during the International Polar Years, and partly to the volume of work required to produce the results. As Sitka has been in continuous operation since 1902, it is ideally suited for such an analysis. Also the use of punched card methods of calculation recently available considerably reduces the labor involved.

The possibility of determination of the lunar variation in the fifty-one years of data is assured as a successful analysis has already been made on a portion of the data by Hughes[4]. This work, however, related only to the declination, and the grouping of the data was made only with regard to season (winter, summer, equinox) and magnetic activity (quiet, ordinary, disturbed, very disturbed). His results will serve as a guide and independent check of the present analysis.

The Chapman-Miller method of analysis uses groups of daily sequences of S + 1 values each (S = 24 when hourly data is used), the last being for the initial hour of the succeeding day. Each daily sequence may be characterized by a number of different parameters and may be combined in many different ways with other sequences according to these parameters. The important grouping for performing an analysis for the luni-solar variation is that by the lunar phase numbers, here given from 0 to 11, each representing the increasing age of the mean moon to the nearest whole hour (i. e. 0 may refer to either the new moon or the full moon). Other groupings of the sequences may also be made such as by season or magnetic activity but these must each be divided into equal lunar phase groups, and hence do not affect the course of the analysis.

The method proceeds by first summing the values of the element for each of the S + 1 (= 25 for the present work) hours over the N_r daily sequences to obtain sequences of 25 hourly group sums g_{sr}. These 25 sums are then harmonically analyzed according to the formulas: $(p = 1, 2, 3, 4)$

4. G. W. Hughes, "The Lunar Diurnal Variation of Magnetic Declination at Sitka (57N 135W) 1902-1922," Thesis (Unpublished) University of Manchester, England, (1927).

$$A_{pr} = \sum_{s=0}^{S} g_{sr} \cos\left(\frac{2\pi s p}{S}\right) + \tfrac{1}{2}(g_{Sr} - g_{or})$$

$$B_{pr} = \sum_{s=0}^{S} g_{sr} \sin\left(\frac{2\pi s p}{S}\right) + \tfrac{1}{2}(g_{Sr} - g_{or}) \cot\left(\frac{\pi p}{S}\right)$$

in which the non-periodic variation is allowed for by the second term in each equation. The sequence of sums $\left[g_{sN} = \sum_{r=0}^{11} g_{sr}\right]$ over the twelve groups is also analyzed in the same way,

$$A_{pN} = \sum_{s=0}^{S} g_{sN} \cos\left(\frac{2\pi s p}{S}\right) + \tfrac{1}{2}(g_{SN} - g_{oN})$$

$$B_{pN} = \sum_{s=0}^{S} g_{sN} \sin\left(\frac{2\pi s p}{S}\right) + \tfrac{1}{2}(g_{SN} - g_{oN}) \cot\left(\frac{\pi p}{S}\right)$$

using the relations

$$A_{pN} = \sum_{r=0}^{11} A_{pr} \quad \text{and} \quad B_{pN} = \sum_{r=0}^{11} B_{pN}$$

to check the results. A secondary harmonic analysis is then performed on each of the sequences of 12 numbers N_r, A_{pr}, and B_{pr} according to the formulas:

$$N_{1A} = \sum_{r=0}^{11} N_r \cos\left(\frac{\pi r}{6}\right) \qquad N_{1B} = \sum_{r=0}^{11} N_r \sin\left(\frac{\pi r}{6}\right)$$

$$A_{pA} = \sum_{r=0}^{11} A_{pr} \cos\left(\frac{\pi r}{6}\right) \qquad A_{pB} = \sum_{r=0}^{11} A_{pr} \sin\left(\frac{\pi r}{6}\right)$$

$$B_{pA} = \sum_{r=0}^{11} B_{pr} \cos\left(\frac{\pi r}{6}\right) \qquad B_{pB} = \sum_{r=0}^{11} B_{pr} \sin\left(\frac{\pi r}{6}\right)$$

The quantities U_p and V_p are then calculated by

$$U_p = (A_{pA} - B_{pB}) - \frac{1}{N}(A_{pN} N_{1A} - B_{pN} N_{1B}) \quad \text{and}$$

$$V_p = (B_{pA} + A_{pB}) - \frac{1}{N}(B_{pN} N_{1A} + A_{pN} N_{1B}) \quad \text{where } N = \sum_{r=0}^{11} N_r$$

Then the numbers L'_n and λ'_n $(n = 1,2,3,4)$ are derived from the formulas

$$L'_n \sin \lambda'_n = \sum_{p=1}^{4} (D_{mpS}/k)\, U_p \quad \text{and}$$

$$L'_n \cos \lambda'_n = \sum_{p=1}^{4} (D_{mpS}/k)\, V_p$$

$$K = 0.4943\, S N \left\{ 1 - [N_{1A}^2 + N_{1B}^2]/N^2 \right\}$$

where

$$m = n - q/29.5306 \ ,$$

and D_{mps} is given by the determinant whose elements are $(-1)^{n-p} d_{mps}$ or

$$\frac{(-1)^{n-p} \sin \pi(m-p)}{S} \left\{ \cot\left[\frac{\pi(m-p)}{S}\right] + \cos\left[\frac{\pi p}{S}\right] \right\}$$

The factors $(-1)^{n-p} d_{mps}$ and D_{mps} are here tabulated for the case of hourly data (S = ~~12~~ 24), q = 2 and for n = 1, 2, 3, 4; p = 1, 2, 3, 4.

TABLE 1

$(-1)^{n-p} d_{mps}$

n	p = 1	2	3	4
1	.92676	.02978	.01049	.00549
2	-.13893	.96084	.04141	.01651
3	-.10113	-.10485	.97247	.04742
4	-.08885	-.06705	-.09322	.97848

D_{mps}

n	p = 1	2	3	4
1	1.0722	-.1476	.1216	-.1191
2	.0347	1.0299	-.1037	.0773
3	-.0105	.0470	1.0176	-.0928
4	.0049	-.0159	.0517	1.0155

The ω'_h and λ'_h must then be corrected for the longitude and the proportions of the data referring to instantaneous values compared with that referring to average hourly values. Finally, the probable errors of the results must be calculated.

In this report the operations described are those in which the group sums g_{sr} are obtained by punched card methods.

2. The Data

The data used are the hourly values of the three magnetic elements H (horizontal intensity), V (vertical intensity) and D (declination) as recorded at the Sitka Magnetic Observatory (geomagnetic coordinates 60°N, 85°W) by the United States Coast and Geodetic Survey. The published values are given for each Sitka day (1^h to 24^h local time) as a tabular base plus positive or negative three or four digit numbers. The horizontal and vertical intensity is given in gammas (10^{-5} Gauss) and the east declination in tenths of minutes. For the period before 1915 the tabular values represent instantaneous readings for that hour whereas the data beginning with 1915 represents the average value for the preceding hour. A summary of the tabular base changes for the data is given in Table 2. The data for 1952 were actually supplied as millimeter scalings rather than absolute values, but the items in this table refer to the calculated absolute values.*

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* See Section 5A.

TABLE 2

Summary of Tabular Base Values

Horizontal Intensity

1^h	January 1, 1902	- December 31, 1904	15400 γ
	January 1, 1905	- December 31, 1952	15000

Declination

16^h	March 17, 1902	- December 31, 1910	29° E.
	January 1, 1911	- December 31, 1932	30°
	January 1, 1933	- April 31, 1940	29°
	May 1, 1940	- May 31, 1940	29° 2'
	June 1, 1940	- June 30, 1946	29°
	July 1, 1946	- December 31, 1951	28°
	January 1, 1952	- December 31, 1952	29°

Vertical Intensity

17^h	January 17, 1905	- December 31, 1906	56400 γ
	January 1, 1907	- December 31, 1912	56000
	January 1, 1913	- December 31, 1918	55500
	January 1, 1919	- December 31, 1930	55000
	January 1, 1931	- December 31, 1952	54500

Besides the hourly magnetic values it was useful for purposes of checking to have the sum of the 24 hourly values for each day. This sum was printed with the data from 1937 to date and was supplied for the period 1926 to 1936 in photostat form by the U. S. Coast and Geodetic Survey. For the period before 1926 a "mean sum" was calculated by multiplying each of the printed daily means (where available) by 24. In cases where any of the hourly values were missing, and consequently no mean value was listed, a true sum was formed by adding the available values.

In addition to the magnetic values it was necessary for grouping the data to have numbers for each day giving information as to the position of sun and moon and the degree of magnetic and solar activity. This set of class numbers, one for each day starting at 18^h Sitka time was prepared as follows: *

1) Season (sn) - a two digit odd number dividing the year into 24 equal parts, starting with 01 for the first division after the winter solstice.

2) Sunspot class (R) - a number from 0 to 11 based on the Zürich sunspot numbers as follows:

Maximum sunspot number	0	15	25	45	60	80	100	130	170	220	280	Inf.
Sunspot class	0	1	2	3	4	5	6	7	8	9	10	11

3) Lunar phase (L) - a number from 0 to 11 according to the increasing age of the mean moon with two sequences per lunation (i. e. 0 may refer to either the new moon or to the full moon.)

4) Lunar Distance (d) - a number from 0 to 7 according to the distance of the moon.

5) Magnetic activity (a) - a number from 0 to 9 based on the International daily magnetic character figure C as follows:

a	C
0	0.0
1	0.1
2	0.2
3	0.3 - 0.5
4	0.6 - 0.9
5	1.0 - 1.2
6	1.3 - 1.4
7	1.5 - 1.6
8	1.7 - 1.8
9	1.9 - 2.0

* These data were derived and accumulated by members of the Geophysikalisches Institut, Göttingen under the direction of Dr. J. Bartels.

As C refers to the Greenwich day 0^h to 24^h, whereas the daily sequences here used refer to the period 18^h to 18^h Sitka time, or 3^h to 3^h Greenwich time, the C values were adjusted to allow for any change of magnetic character betwee the Greenwich day and the adopted Sitka day.

3. Punching of the Data

The tabular values were punched into electric accounting machine cards with each card containing the data for one day per element as follows:

1) Column 1 - The month of the year. e. g. Jan. = Y, Feb. = X, Mar. = 0, ----- Dec. = 9.

2) Columns 2 and 3 - Day of the month. (There was also punched a "33" card containing the monthly means.)

3) Columns 2 and 3, row Y - These two punches differentiated between the magnetic elements, D had a Y punch in 3; V had a Y punch in 2; and H had no punch in either.

4) Columns 4-75 - The 24 three-digit tabular values with the first hour in columns 4, 5, 6 up to the 24th hour in columns 73, 74, 75. An X punch in the hundreds position (4, 7, ----- 73) indicated that the value was negative (less than the tabular base value) and a Y punch indicated that 1000 should be added to the three digit value. This method of punching four digit numbers into a three-digit field was possible as no tabular values exceeded 1999. If the tabular value was missing the columns were left blank.

5) Columns 76-80 - The true sum, or "mean sum" if the former were not available.

6) Columns 75-80 - The year was indicated by a binary code in the Y row. e. g. for 1952, $(52)_{10} = (110100)_2$

The month, day, 24 values, and sum were keypunched; the element and year codes were gangpunched on a 513 reproducer. The month, day and sum were checked on a verifying machine.

At the same time that the punching was done a listing was made of the cards with missing values and of those with values over 999.

In addition to the primary set of cards (A) a second set of cards (B) was punched containing the classifying numbers as follows:

1)	Columns	1 and 2	- The year reckoned from 1900.
2)	"	3	- Month of the year as on Set A.
3)	"	4 and 5	- Day of the month.
4)	"	6 and 7	- Season number (sn).
5)	"	8	- Sunspot class number (R).
6)	"	9	- Lunar phase number (L).
7)	"	10	- Lunar distance number (d).
8)	"	11	- Magnetic activity number (a).

Set B was checked directly on the verifying machine.

The total time taken in punching set A and verifying the month, day and sum (88 column punches per card) was about 1540 hours. As there were about 4,500,000 key punches involved this would average about 3000 keypunches per hour. This is considerably less than the 8000 estimated on the basis of straight-forward punching rates quoted by IBM but is not unreasonable for data of the present kind.

4. Verification of the Magnetic Values

The procedure used to check the punched hourly magnetic data was to compare the sums of the 24 values with the punched true sum or mean sum. The difference of the former sums should be exactly zero while that for the latter, due to rounding of the last digit in the daily means, should be not more than 12. A 407 accounting machine* was employed for this purpose.

At the outset of the operation it appeared that the 407 could perform the addition without reproducing part of the data onto another card. However, it was found that the method of indicating four-digit values (punching a Y in the same column that an X is used to indicate a minus sign) made this impossible so that two cards per day were needed. The reproduction of the last 12 values onto a new card was done on a 513 reproducer at the same time as the gang-punching of the year and element codes. The reproduced set (Set A') then contained the month, day, element, and year code as in Set A but the last 12 hourly values appeared in columns corresponding to the first 12 values of set A (columns 40-75 were then blank). The reproduction was self checking by a set of comparing magnets and the gang punching was checked by looking at the last card of each group. Set A was also given a Y punch in column 12 to distinguish it from set A'. Sets A and A' were then merged on a collating machine, each card of set A' appearing behind the corresponding card of set A. This operation was checked by noting the order of the last pair of cards for each year as they came from the collator.

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* Use of IBM machines for this phase of the work was kindly permitted by the 27th Statistical Services Flight, Elmendorf Air Force Base, Anchorage, Alaska.

A 407 Accounting Machine was then wired* to perform the addition of the 24 daily values. This operation took two read cycles (using the same digit selectors on each cycle), four crossfooting cycles, and one cycle to take the difference between the crossfooted sum and the punched sum for a total of seven machine cycles per pair of cards. There was then printed the month and day numbers, the 24 hourly values, the calculated sum of the 24 values, the punched sum and the difference. As it was impossible to take the Y punches in the hundreds positions into account, the difference was increased by 1000 N when there were N four-digit values appearing in a card pair. The four-digit cards were then easily located and removed from the set for special processing.

The printed results were then used to find and correct errors in the original punching.

The total time required to punch and verify both sets of data (A and B), with 21% of the punching verified directly and the remainder by the above summation, amounted to about 2020 hours. As about 4.33×10^6 columns of information were produced, this is about 2000 keypunches per working hour. If the data were all verified directly on a verifying machine, the rate would have been one half of the actual punching rate or 1470 per hour. Hence a 27% saving in time was achieved in the overall operation by this method of verification.

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* The board wiring for this operation was done by Maj. C. J. Winnie of the 27th Statistical Services Flight and V. B. Mulley of the IBM Corp.

The possible disadvantages of checking by this method arise first from compensating errors and secondly from the errors whose effect, where the mean sums were used, was to give a total within 12. For those cards in which true sums were used only the compensating errors are possible. However, as the probability of an error is small, the chances that there would be two equal and opposite errors on the card is negligible. A count of the errors in 2/3 of the data (H and D) shows that there was a total of about 7 punching errors per 10,000 three-digit numbers. A sample composed of V cards for the years 1927-1951 (for which true sums were available) showed that the numbers of errors in punching that resulted in differences no greater than 12 and hence not detectable in the data 1902-1925 (mean sums only) was about 3 in 10,000. From this it may be estimated that in all of the data from 1902 through 1925 there are only 200 undetected errors none of which differ more than 12 from the actual value. There were only 7 errors made by the 407 Accounting Machine for all of the data.

5. Other Preliminary Operations

At this point in the project it was necessary to perform various preliminary operations on the punched data to get it into final form for the analysis. For these one needed to consider in detail each step of the calculation with the particular machines available at the Watson Scientific Computing Laboratory where the group sums were to be made. Originally it was thought that it might be desirable to calculate the harmonic coefficients for all three elements for each day and enter these onto the cards containing the classification material (set B). These cards could then be sorted and added in various combinations of the daily characterization numbers. However, an estimate of the time required for this operation on the best equipment available (Card Programmed Calculator, Model II) exceeded a thousand machine hours and was hence discarded. A second method considered, which would simplify the further analysis by reducing the number of digits, would be to punch successive hourly differences and then derive harmonic coefficients for these. However, an investigation of the machine time required showed this also to be impractical. The reasons why the above approaches would have required such long calculation times involved two factors. The first of these was that the daily characterization numbers referred to the "adopted" day beginning 18^h Sitka time of the previous day. Thus any calculation on each card of the original set required that information be stored from one card to the next. Secondly, operations in which results are summary punched for each card cannot exceed 30 cards per minute. The method then decided upon was to transfer the data for each "adopted" day directly to cards containing the classifying information using a reproducing punch (100 cards per minute) and then form the group sums from these.

With the procedure in mind it was then possible to get the original punched data into final form for transference to the working card set. The various operations leading to this working set are described below.

A. Conversion of the 1952 Data

The 1952 data were given in the form of hourly millimeter scalings, the daily sums of these scalings, and a list of the scale and base line changes for the year. The cards were punched with these millimiter scalings identically as if they were absolute values as in set A, except that the X punch for minus numbers was overpunched in the units position rather than the hundreds position. This was done so that the conversion to absolute values could be on an electronic calculator which has automatic sign control for X punches in the units position. However, two 602-A calculating punches were used as they were more available at the time. The procedure was first to check the original punching by adding across the cards as before, to convert these to absolute tabular values, an finally then to check the conversion by a similar addition of the hourly values.

The formula for the conversion of the hourly millimeter scalings is

$$TV = Sd + (B - TB)$$

where TV = tabular value to be punched,
S = scale value,
d = ordinate in millimeters,
B = base line value,
and TB = tabular base.

For the conversion of the daily sums the above formula becomes

$$TV = S\Sigma d + 24(B - TB)$$

However, as each of the tabular values was rounded to three digits their sum could not be expected to equal exactly the converted daily sum. Thus as the maximum uncertainty in each of the 24 TV's and also of the converted sum is $\pm$ 0.5 units, there is a possible difference of 13 between the true sum and the converted sum. The checking by addition could thus only detect errors of conversion resulting in differences greater than 13.

The details of the conversion and checking operations are as follows:

(1) The A' set containing the last 12 hourly values for each card was prepared on a reproducing punch as before.

(2) Sets A and A' were then merged on a collator with each card of A' following the corresponding card of A.

(3) A 602-A plugboard was wired to add the 12 values on the first card to the 12 values on the second card, add these 12 sums together, subtract the punched total, and then punch the result on the second card.

The merged cards were then run through the 602-A calculator.

(4) The checking and correcting of errors was then done by sorting out the A' set by the identifying X punch in column 22 and needling them to determine differences which were

not zero. This was possible for this part of the data as all of the sums were exact. The cards containing the errors were then removed and corrected. The A' set was then discarded.

(5) The corrected values of Set A were reproduced onto two sets of cards which will be referred to as A_1 and A_2. A_1 contained the month, day, first twelve values of each A card (columns 3-39) and the sum (columns 76-80). Set A_2 contained the month, day, and the last twelve values (columns 3-39). Sets A_1 and A_2 were then merged, with each A_2 following the corresponding A_1.

(6) A set of master cards was keypunched each containing the base line and scale values and the date on which these changes occurred. These were then merged with the A_1 A_2 set, each master card preceding those to which it referred.

(7) Three 602-A plugboards were then wired to convert the data to the required absolute values. The constants were read from each master card for use on the following set of detail cards. Then the first six values were read from the detail card into storage units and multiplied by the scale value. The base line constant was added to the product and the sum then tested to determine whether it was positive or negative. A $\pm$ 5

digit was read into the counter position to be dropped according to the results of this negative balance test. The rounded three-digit values were then punched into columns 40-57 with an X value in the hundreds position if negative. The cards were run through a second time with the calculation done as before but with the second six values read from the detail cards and the result punched into columns 58-75.

A third plugboard was wired to convert the punched sum by reading from A_1, multiplying by the scale value, adding 24 times the base line constant and punching the result in columns 76-80 of A_2.

(8) The converted values were then reproduced onto another set of cards producing a new A and A' set. Checking of the conversion was done by adding the 12 converted values of each card, subtracting the converted sum and punching the difference in the A' set. The latter set was then removed and the differences tabulated on a 405 accounting machine. Those differences greater than 13 were checked and the values corrected.

B. Removal of Extraneous Cards

As it was decided to reproduce the data from the original set onto cards containing the classification material before summing, the A' set was no longer useful and was consequently sorted from the A set and discarded.

It was originally thought that the monthly mean cards would form a basis for crosschecking the punching of the original A set where the monthly sums were not available. However, as the checking operation proceeded it was found not worthwhile to set up the machines for finding the few remaining errors. These cards (33 punches in the day field) were removed from the A set on a collator.

C. Four Digit Values

During the checking of the punched values using the printed differences, those cards containing four digit numbers (about 400) were manually pulled out and kept together. The use of the hundreds position in each field for both minus numbers (X punch) and four-digit values (Y punch) proved a difficulty as the machines had no means of distinguishing between X and Y punches. It was decided to indicate four-digit values by either an X or Y punch in the tens position of each field (the selectors in the 418 adding machine were picked up by either X or Y impulses). This was readily done on those cards that did not contain negative numbers by transfering the punches on a reproducer. This involved running each set of cards through four times, reproducing six values in each run. Those cards containing negative as well as four-digit values were run through a reproducer which punched only the numerical fields, after which the X and Y punches were then entered in the proper places on a keypunch.

These modified cards were then replaced in the original set by hand. This operation was done manually rather than on the collator not only because of the small concentration but also because the collator would not distinguish between the Y, X, and O punches used in column 3 for the months January, February, and March.

D. Interpolation of Missing Values

Another problem to consider was that several hundred of the cards contained blank fields due to the absence of data for these hours. The records were incomplete due to either exceptional magnetic disturbance or to the temporary suspension of observations during instrument adjustment or failure, the latter being more frequent in the earlier data. In the summing operation blank columns would appear as zero so that it was necessary either to insert a mean value or discard the cards. It was then decided that it would be desirable to interpolate where one or two consecutive values were missing but to discard those cards containing more than two. As there was no convenient way either to remove the cards or interpolate by machine methods, it was necessary to perform both of these operations manually.

A listing of those days containing missing values was made from the data and those cards for which interpolation was possible were removed from the set. The values were linearly interpolated and the cards put back in the proper sequence.

The removal of data in which more than two consecutive values were missing and hence not interpolated could not be done on the A set due to the shift of data from set A to set B. For example any data missing in the interval 19^h to 24^h Sitka time for day D required the pair of cards for that element for day D + 1 to be discarded but would not affect day D. Thus the A set was kept intact and the listing of missing values was used to remove cards from set B.

At this point the original punched set A was practically ready for the transfer of data to the working set B. However, many cards had been removed and replaced from the original set, mostly by hand, for checking, for interpolating, etc. To check for missing cards, duplicate cards, and cards out of order it was thought adequate to make a card for card comparison between the H, D, and V sets. This comparison was made on a 519 reproducer by wiring from the comparing and gangpunch brushes of columns 1, 2, and 3 to corresponding comparing magnets. The H and D sets, being the longest series, were compared first, and then the corrected D set was compared with V.

E. Preparation of Set B

The original punched set B contained only the date and the eight daily characterization numbers. As the magnetic data were to be transferred to cards containing these numbers there needed to be two cards per day or a total of six sets reproduced from the original. These sets, which shall be designated H_1, H_2, D_1, D_2, V_1, V_2, were to be identical in the date and characterization numbers but with punches to differentiate between the elements H, D, V and the part of the day (subscript 1 = first half; 2 = second half). In addition punches were added to indicate the average yearly solar activity (see section 6) and others to indicate whether the data referred to average or instantaneous values. The details of the punching is given as follows:

Column 12 - X punch for first half of Day (H_1, D_1, V_1).
" 22 - X punch for second half of Day (H_2, D_2, V_2).
" 78 - Average yearly solar activity 2, 4, or 6.
" 79 - X to indicate instantaneous values, 1 to indicate hourly averages.
" 80 - Horizontal intensity = 1; Declination = 3; vertical intensity = 5.

The above numbers were emitted into the six sets in addition to the common information in the first 11 columns. Actually six new sets were finally made as the original B set became so worn that it was thought that difficulty might be encountered if it were used in the subsequent operations. Due to frequent card jams when reproducing two of the sets, it was found necessary to make a card for card sequence check of these sets against their corresponding A set cards. This check also indicated any omissions, duplications or sequence errors in the B set.

The hourly magnetic values of set A were then punched into the six B sets as follows:

Run 1 - Values 19 through 24 for day D of set A were reproduced into the first six positions of sets B_1 (columns 24 through 41) for day D + 1

Run 2 - Values 1 through 6 for day D of set A were reproduced into the second six positions of sets B_1 (columns 42 through 60) for day D

Run 3 - Values 7 through 12 for day D of set A were reproduced into the first six positions of sets B_2 (columns 24 through 41) for day D.

Run 4 - Values 13 through 19 for day D of set A were reproduced into the next seven positions of sets B_2 (columns 42 through 63) for day D.

The above operations then resulted in two cards per element per adopted day with 25 hourly values starting with 19^h Sitka time. * This group of operations was in general checked directly by comparing magnets from the respective comparing and gangpunching brushes. The only variation used was in the process of transferring the last six numbers from the A card for day D to the first half of card B_1 for day D + 1. In this operation the B cards were fed in one ahead of the A cards. While the punching and comparing proceeded normally the only way to check whether the data was being transferred to the proper card was to compare the date (month and day) of the card at the gangpunch brushes with the one at the reproducing brushes. The previously entered set of punches in columns 78 and 79 was also checked during the transfer operations by comparing the punched values with emitted pulses, wiring for the latter being changed frequently as needed.

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* For the average hourly values, which comprise at least three-quarters of the data, the number given for 19^h represents the average from 18^h to 19^h.

The cards containing missing (non-interpolable) data were then removed manually according to the previously prepared list. The original number of cards were 18627 (H), 18554 (D) and 17515 (V). Of these 307 (H), 197 (D) and 264 (V) were removed. To check that the sets were then ready for the formation of group sums a card-for-card comparison of the common information was made between the two sets for each element.

6. Grouping of the Data

The grouping of the data was done so as to take into account all factors affecting the lunar and solar daily variations. A decision as to the size of each group was made on the basis of the estimated magnitude of the component sought and the probable error of the determination. The magnitude may be estimated both from previous work on the Sitka data and by extrapolating results at other stations. The probable error may be likewise estimated from past work, but as its magnitude is a result of random or non-periodic variations this is more uncertain. Where doubt existed the tendency was to keep the groups small as it remained possible to combine the results if the probable errors for single groups were found too large. The largest probable error usually allowed in work of this type is one-third the magnitude of the result found .

To make groupings of the data according to the various classification numbers it was necessary to determine the distributions of these numbers within the sets. As the years were divided into 24 equal seasons one could assume that there would be an even distribution of this parameter. Likewise the lunar phase and distance numbers would be rather evenly divided in any large group of data. However, a count was taken of the number of days of each of sunspot class number and of each magnetic activity number within each of their respective groups.

The method of finding the frequency distribution of numbers within a given set of cards was to wire an accounting machine (in this case a type 405) to accumulate the number of digits punched in a particular column and print out the total when impulsed by a particular card. This was done by channeling the digits through a field selector, the outlet hubs of which were wired to the pickup hubs of pilot selectors. The hubs of these selectors were then used as switches to allow a 1 pulse to add into counters if the corresponding selectors were transferred. One counter was used to accumulate the total number of card. Thus the number printed from the last counter should be the sum of the totals from the others. The speed of this operation was slightly less than 150 cards per minute.

The first distribution determined was that for the magnetic class numbers a. For convenience of checking the sum cards were placed after each year. After completing this run the wiring was changed to read in the sunspot class numbers and another run was made. In this case the 11 punches for the high sunspot classes were not counted as the 405 does not recognize Y punches.

When the checking of totals was done for the above, it was apparent that some of the selectors, especially for the eight digit, were not transferring. However, as only a general idea of the distribution was required, and as the number of eights could be estimated from the difference between the totals, the results were left inexact.

The percentage distribution of the _a_ numbers in each year was found to remain substantially constant over the 51 years, the maximum being generally in the group a = 4. The distribution of R class numbers was much more variable over the period; the most abundant group ranged from 0 for years of sunspot minimum to 7 or 8 during years of high solar activity. It was also found that while there were practically no days in the less active years with a high R number, there were a number of days in the active sunspot years with a low R number. As the magnetic variations might depend on the general condition of the sun rather than on the sunspot class number for a given day, it was thought desirable to put a number on each card to indicate whether the year was one of low, medium, or high sunspot activity. The numbers (M) 2, 4, 6 were then assigned to the cards of a particular year according to the mean yearly sunspot number as given in Table 3. The division is made as follows:

M	Mean sunspot numbers	Number of years per group
2	1 - 30	17
4	31 - 64	18
6	65 - 152	16

TABLE 3

Year	Annual Mean Sunspot Number	Yearly Class Number M
1902	5	2
1903	24	2
1904	42	4
1905	64	4
1906	54	4
1907	62	4
1908	48	4
1909	44	4
1910	19	2
1911	6	2
1912	4	2
1913	1	2
1914	10	2
1915	47	4
1916	57	4
1917	104	6
1918	81	6
1919	64	4
1920	38	4
1921	26	2
1922	14	2
1923	6	2
1924	17	2
1925	44	4
1926	64	4
1927	69	6
1928	78	6
1929	65	6
1930	36	4
1931	21	2
1932	11	2
1933	6	2
1934	9	2
1935	36	4
1936	30	6
1937	114	6
1938	110	6
1939	89	6
1940	68	6
1941	48	4

TABLE 3 (Cont'd)

Year	Annual Mean Sunspot Number	Yearly Class Number M
1942	31	4
1943	16	2
1944	10	2
1945	33	4
1946	93	6
1947	152	6
1948	136	6
1949	135	6
1950	83	6
1951	69	6
1952	31	4

Having punched the M numbers into the cards and removed those with missing data the H_1 set was sorted into twelve groups according to the sunspot class number. These were then run through the 405 machine wired to obtain the distribution of the magnetic activity numbers a within each R group. Table 4 gives the result of this run.

TABLE 4

Distribution of Magnetic Activity Numbers Within Each R Group

(H_1)

R \ a	0	1	2	3	4	5	6	7	8	9	Total
0	181	391	276	610	660	329	117	58	28	8	2658
1	153	317	261	557	632	341	120	60	34	13	2488
2	110	211	201	422	524	267	96	57	33	8	1929
3	174	332	272	669	823	426	164	100	67	14	3041
4	99	182	157	444	518	270	116	80	29	25	1920
5	107	212	169	448	527	309	119	80	41	30	2042
6	54	138	118	368	429	225	73	59	30	18	1512
7	58	144	126	316	380	223	98	52	36	21	1454
8	35	78	85	211	206	115	50	42	25	17	864
9	7	16	30	99	91	40	24	7	12	3	329
10	0	2	2	20	23	9	3	5	3	2	69
11	0	0	0	2	5	5	1	1	0	0	14
Sums	978	2023	1697	4166	4818	2559	981	601	338	159	18320

The wiring was then changed to obtain the distribution of M numbers, the result being given in Table 5.

TABLE 5

Distribution of M Numbers Within Each R Group

(H_1)

R	2	4	6	Total
0	2493	162	3	2658
1	1761	679	48	2488
2	876	931	122	1929
3	683	1823	535	3041
4	151	1070	699	1920
5	58	909	1075	2042
6	30	478	1004	1512
7	10	306	1138	1454
8	0	88	776	864
9	0	6	323	329
10	1	0	68	69
11	0	0	14	14
Sums	6063	6452	5805	18320

With this information it was possible to divide the data suitably. This was done so that the number of cards in each group sum sequence would in general be greater than 40 but less than 200. The various groupings are given in Table 6.*

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* A parenthesis around a series of numbers indicates that the corresponding groups were combined. When no numbers appear in a particular column, no division was made on this parameter.

TABLE 6

(1) Magnetic activity at 24 different seasons; a-sn

Index	sn	R	L	d	a	M
0001-0024	01-47				0	
0025-0048	"				1	
0049-0072	'				2	
0073-0096	'				3	
0097-0120	"				4	
0121-0144	"				5	
0145-0168	"				6	
0169-0192	"				7	
0193-0216	"				8	
0217-0240	"				9	

(2) Sunspot activity at 24 different seasons; R-sn

0251-0274	01-47	0				
0275-0298	"	1				
0299-0322	"	2				
0323-0346	"	3				
0347-0370	"	4				
0371-0394	"	5				
0395-0418	"	6				
0419-0442	"	7				
0443-0466	"	8				
0467-0490	"	9				
0491-0514	"	10				
0515-0538	"	11				

(3) Sunspot activity (6 R groups and 3 M groups) and magnetic activity (2 or 3 groups) at 8 or fewer seasons; R-M-a-sn

0600-0602	(47,1,3)	0			(0,1,2) (3,4) (5,--9)	
0603-0605	(5,7,9)	0			"	
0606-0608	(11,13,15)	0			"	
0609-0611	(17,19,21)	0			"	
0612-0614	(23,25,27)	0			"	
0615-0617	(29,31,33)	0			"	
0618-0620	(35,37,39)	0			"	
0621-0623	(41,43,45)	0			"	
0624-0626	(47,1,3)	1			"	

Index	sn	R	L	d	a	M
0627-0629	(5,7,9)	1			(0,1,2) (3,4) (5,--9)	
0630-0632	(11,13,15)	1			"	
0633-0635	(17,19,21)	1			"	
0636-0638	(23,25,27)	1			"	
0639-0641	(29,31,33)	1			"	
0642-0644	(35,37,39)	1			"	
0645-0647	(41,43,45)	1			"	
0648-0653	(47,1,3)	(2,3)			"	2,4
0654-0655	"	"			(0,--3) (4,--9)	6
0656-0661	(5,7,9)	"			(0,1,2) (3,4) (5,--9)	2,4
0662-0663	"	"			(0,--3) (4,--9)	6
0664-0669	(11,13,15)	"			(0,1,2) (3,4) (5,--9)	2,4
0670-0671	"	"			(0,--3) (4,--9)	6
0672-0677	(17,19,21)	"			(0,1,2) (3,4) (5,--9)	2,4
0678-0679	"	"			(0,--3) (4,--9)	6
0680-0685	(23,25,27)	"			(0,1,2) (3,4) (5,--9)	2,4
0686-0687	"	"			(0,--3) (4,--9)	6
0688-0693	(29,31,33)	"			(0,1,2) (3,4) (5,--9)	2,4
0694-0695	"	"			(0,--3) (4,--9)	6
0696-0701	(35,37,39)	"			(0,1,2) (3,4) (5,--9)	2,4
0702-0703	"	"			(0,--3) (4,--9)	6
0704-0709	(41,43,45)	"			(0,1,2) (3,4) (5,--9)	2,4
0710-0711	"	"			(0,--3) (4,--9)	6
0712	(47,1,3)	(4,5)				2
0713-0716	"	"			(0,--3) (4,--9)	4,6
0717	(5,7,9)	"				2
0718-0721	"	"			(0,--3) (4,--9)	4,6
0722	(11,13,15)	"				2
0723-0726	"	"			(0,--3) (4,--9)	4,6
0727	(17,19,21)	"				2
0728-0731	"	"			(0,--3) (4,--9)	4,6
0732	(23,25,27)	"				2
0733-0736	"	"			(0,--3) (4,--9)	4,6
0737	(29,31,33)	"				2
0738-0741	"	"			(0,--3) (4,--9)	4,6
0742	(35,37,39)	"				2
0743-0746	"	"			(0,--3) (4,--9)	4,6
0747	(41,43,45)	"				2
0748-0751	"	"			(0,--3) (4,--9)	4,6

Index	sn	R	L	d	a	M
0752-0754	(47, 1, 3)	(6, 7)			(0, 1, 2) (3, 4) (5, --9)	
0755-0757	(5, 7, 9)	"			"	
0758-0760	(11, 13, 15)	"			"	
0761-0763	(17, 19, 21)	"			"	
0764-0766	(23, 25, 27)	"			"	
0767-0769	(29, 31, 33)	"			"	
0770-0772	(35, 37, 39)	"			"	
0773-0775	(41, 43, 45)	"			"	
0776	(47, 1, 3)	8				
0777	(5, 7, 9)	"				
0778	(11, 13, 15)	"				
0779	(17, 19, 21)	"				
0780	(23, 25, 27)	"				
0781	(29, 31, 33)	"				
0782	(35, 37, 39)	"				
0783	(41, 43, 45)	"				
0784	(41, --7)	(9, 10, 11)				
0785	(17, --31)	"				
0786	(9, --15, 33, --39)	"				

(4) <u>Lunar subgroups (12) for 6 magnetic activity groups and 8 (or fewer) seasons; L-a-sn</u>

0800-0811	(47, 1, 3)		0, --11		(0, 1, 2)	
0812-0823	(5, 7, 9)		"		"	
0824-0835	(11, 13, 15)		"		"	
0836-0847	(17, 19, 21)		"		"	
0848-0859	(23, 25, 27)		"		"	
0860-0871	(29, 31, 33)		"		"	
0872-0883	(35, 37, 39)		"		"	
0884-0895	(41, 43, 45)		"		"	
0896-0907	(47, 1, 3)		"		3	
0908-0919	(5, 7, 9)		"		"	
0920-0931	(11, 13, 15)		"		"	
0932-0943	(17, 19, 21)		"		"	
0944-0955	(23, 25, 27)		"		"	
0956-0967	(29, 31, 33)		"		"	
0968-0979	(35, 37, 39)		"		"	
0980-0991	(41, 43, 45)		"		"	

Index	sn	R	L	d	a	M
0992-1003	(47,1,3)		0,--11		4	
1004-1015	(5,7,9)		"		"	
1016-1027	(11,13,15)		"		"	
1028-1039	(17,19,21)		"		"	
1040-1051	(23,25,27)		"		"	
1052-1063	(29,31,33)		"		"	
1064-1975	(35,37,39)		"		"	
1076-1087	(41,43,45)		"		"	
1088-1099	(41,--7)		"		5	
1100-1111	(17,--31)		"		"	
1112-1123	(9,--15, 33,--39)		"		"	
1124-1135	(41,--7)		"		(6,7)	
1136-1147	(17,--31)		"		"	
1148-1159	(9,--15, 33,--39)		"		"	
1160-1171			"		(8,9)	

(5) <u>Lunar subgroups (12) for 6 sunspot groups (in some cases subdivided according to mean annual solar activity) and 4 (or fewer) seasons</u>

Index	sn	R	L	d	a	M
1200-1211	(43,47,1,-5)	0	0,--11			
1212-1223	(7,--17)	"	"			
1224-1235	(19,--29)	"	"			
1236-1247	(31,--41)	"	"			
1248-1259	(41,--7)	1	"			2
1260-1271	(17,--31)	"	"			"
1272-1283	(9,--15, 33--39)	"	"			"
1284-1295		"	"			(4,6)
1296-1307	(43,--5)	(2,3)	"			2
1308-1319	(7,--17)	"	"			"
1320-1331	(19,--29)	"	"			"
1332-1343	(31,--41)	"	"			"
1344-1355	(43,--5)	"	"			4
1356-1367	(7,--17)	"	"			"
1368-1379	(19,--29)	"	"			"
1380-1391	(31,--41)	"	"			"
1392-1403	(1,--47)	"	"			6
1404-1415		(4,5,6)	"			2
1416-1427	(43,--5)	"	"			4

Index	sn	R	L	d	a	M
1428-1439	(7,--17)	(4,5,6)	0,--11			4
1440-1451	(19,--29)	"	"			"
1452-1463	(31,--41)	"	"			"
1464-1475	(43,--5)	"	"			6
1476-1487	(7,--17)	"	"			"
1488-1499	(19,--29)	"	"			"
1500-1511	(31,--41)	"	"			"
1512-1523	(43,--5)	(7,8)	"			
1524-1535	(7,--17	"	"			
1536-1547	(19,--29)	"	"			
1548-1559	(31,--41)	"	"			
1560-1571	(1,--47)	(9,10,11)	"			

(6) <u>Lunar subgroups (12) for 2 magnetic activity groups and 8 lunar distance groups at 3 seasons; L-d-a-sn</u>

1600-1695	(41,--7)		0,--11	0,--7	(1,2,3)	
1696-1791	(17,--31)		"	"	"	
1792-1887	(9,--15, 33,--39)		"	"	"	
1888-1983	(41,--7)		"	"	(4,5)	
1984-2079	(17,--31)		"	"	"	
2080-2175	(9,--15, 33,--39)		"	"	"	

The first 240 groups (a-sn) were selected according to magnetic activity (a) and season number (sn). These groups were chosen not only to show the dependence of the solar daily variation upon season and magnetic activity, but also to provide sums which would be useful for checking the later work. The second set of groups (R-sn) was selected according to the daily solar activity (class numbers R) and season, and was used primarily for purposes of checking Whereas the a-sn sums can be used to illustrate the effect of magnetic activity and season on the solar daily variation the R-sn sums would not be so useful.

This is because the effect of the R variation is complicated by that of the magnetic activity on the days of high a number within each R group. Hence to obtai a better idea of the effect of increasing solar activity another grouping (R-M-a-sn) was made in which the days were divided first into R groups, a few of which were combined, and then into eight season groups. The seasonal groupings were made in such a way that the equinoxes and solstices would fall as nearly in the center of their groups as possible. Then as the days of median R number (R = 2, 3, 4, 5) were distributed over years of widely differing solar activity a further division was made according to the M numbers. The resultin groups were then divided into two or three groups of magnetic activity dependin on their size. No division by M was made for the other R groups as they were selected mainly from years of about the same solar activity. For the larger R numbers fewer divisions were necessary as the groups contained fewer days.

The remainder of the groupings were made to obtain the sums needed to determine the luni-solar daily variation. The first grouping, L-a-sn, divided the data into five a groups each in 8 (or fewer) seasons, and finally into the twelve lunar phase groups. The seasonal division for the larger a groups (a = 0-2, 3, and 4) was eight-fold but the a = 5 and a = 6, 7 groups had fewer days an were divided into only three seasons. No seasonal division was made for the a = 8, 9 group. The division of the year by thirds was made so that the two equinoxes were combined into one group while the winter and summer solstices formed the other two. In all seasonal divisions the number of sn groups within each yearly fraction were the same.

The next division of the data, L-R-M-sn, was made in the same way as the set (3) of R-M-a-sn groups, except that it did not include any magnetic activity subdivision, and also owing to the extra L subdivision the other groups could not be as small. Thus the year was divided at most into four parts and more of the R groups were combined.

The last division of the data (L-d-a) was made to determine the effect of the variable distance of the moon on the luni-solar variation. Owing to the sma magnitude of the lunar variation in the vertical force the cards were grouped on the assumption that only the horizontal intensity and declination would be analyz in this way. Even so it was thought practical to use only the low and medium magnetic activity groups. The lunar distance grouping was eight-fold.

7. Formation of the Group Sums

Having prepared the six working sets of cards and decided upon the groupin of the data it was necessary to wire the calculators to perform the additions for the group sums g_{sr} and the numbers N_r of days in each group. In addition it was necessary to form the subnumbers N_r' and N_r'' of days in each group for which either instantaneous hourly values were given (N_r') or for which hourly mean values were given in the original tables of data (so that $N_r' + N_r'' = N_r$). In general this required the summation of 12 (sets B_1) or 13 (sets B_2) magnetic values of three or four digits plus the card counts resulting in N_r' and N_r''. The equipment with which the summation was done was a Card Programmed

Electronic Calculator Model II (hereafter referred to as the CPC). This particular unit consists of a 418 accounting machine, a 605 electronic calculato a 527 gang summary punch, and two mechanical storage units, the last not bein used in this calculation. Operations to be discussed will refer to these type numbers.

The 418 was used to read the data from the cards, form most of the sums and print the results of all CPC operations. The remainder of the sums had to be made by the 605.

The first problem to be considered was that of counter capacity. If one assumes the largest group to number say 300 days and the largest average hourly value to be 1000, the number of digits needed in the sum would be those for a total of 300,000, that is six. If negative values are encountered there normally must be another counter position available to indicate the sign of the result. However, as any negative numbers encountered would certainly be les than 10,000, six counter positions should be all that would be needed. By appropriate counter coupling, the maximum number of such columns of values that could be added in the 418 was 12, leaving the 13th value and the card coun to be added in the 605. The total number of digits that might appear in the result would be 86, counting Nr' as two digits and N_r, N_r'' as three each. As there are only 89 type bars, and as allowance must be made for spacing, eithe the printing would need to be on two lines, which would take an extra program step, or the number of digits in each sum would need to be reduced. An estimate of the probable error of the results indicated that two digits could be rounded from the g_{sr} with no loss of accuracy. Since the results might later need to be combined it was thought best to drop only one digit in this operation and perhaps another when the analysis is made on the g_{ir} .

The next problem considered was a method of allowing for the four digit values as identified by an X punch in the tens position of each field. These were readily allowed for by impulsing the 12-11 pickup of a pilot selector at the second brush reading with this X punch to allow a 1 digit to read through the transferred side of the selector into the fourth counter position on the third reading. Thus each card was read effectively as if it had a four digit field.

The last major problem was that of the tabular base changes. As only the daily variations are significant in this analysis a method frequently used is to subtract the first value of each sequence from each value of that sequence and then form the group sums of these differences. Not only are tabular base differences allowed for but also the numbers to be harmonically analyzed are much smaller. At the present writing it appears that this would have been feasible, although at the time an investigation of the procedure erroneously indicated that it would have lengthened the calculation considerably. As there were two cards per day it would have been necessary to make a separate run on the reproducers to punch the first value of B_1 onto B_2. The 12 (B_1) or 14 (B_2) magnetic values would then be summed and a separate machine cycle taken before totalling the counters to subtract this first value from the others. The plugboard wiring for the B_1 and B_2 sets would need to be different, or the B_1 set would need the first value punched into the same position as in B_2.

The method used was similar to the above except that constants were added to each card so that all results were adjusted to the same tabular base. The tabular bases used were 15000 γ for H, 54500 γ for V and 28° E for D. No constants were added to the horizontal intensity as the punched values already referred to a base of 15000 γ. Actually the data for the period 1902-1904 were printed relative to the base 15400 γ but 400 γ was added when the punching was done. The constants K added to the declination and vertical intensity for each period of the data are given in Table 7.

TABLE 7

Declination - 28° E

K	Period Covered *
000	(4) 1946 - 1951
600	1902-1910, 1933-(1)1940,(3)1940-(3)1946,1952
620	(2) 1940
1200	1911 - 1932

Vertical Intensity - 54500 γ

K	
000	1931 - 1952
500	1919 - 1930
1000	1913 - 1918
1500	1907 - 1912
1900	1905 - 1906

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* Numbers in parenthesis refer to the month in the punched code. e.g. 3 = June
When no parenthesis appears, the years are complete.

As the summation was to be done on groupings of cards not in chronologica] sequence it was necessary to have identification on each card for the proper constant to be added. Originally it was thought that there would be no storage space available to permit reading the constant K from each card; K would then need to be emitted from the digit emitter through suitable selectors into a counter. This involved picking up two field selectors, one with each digit of the year number, and digit selectors to split the months columns of those years that needed differentiating between the months. These selectors were then chain wired so that the appropriate time interval picked up selectors to provide channels for K. After wiring this rather complicated system, a back circuit appeared so that the counters did not total properly. In the subsequent checking to eliminate this condition it was noted that there was effectively one storage unit in the 605 not in use, so that the constants could be entered directl from the cards. Although it was later discovered that the difficulty was not with this section of the board the selector network was replaced and the constants gangpunched into the cards (0.1 K punched into columns 63-65). Not only did this system simplify checking operations but it eliminated the wiring changes that would have been necessary for the different magnetic elements.

The final calculation was then done in three 418 program steps. The X and Y punches were read at the second brush station to provide control for signs and four-digit values and to impulse a pilot selector to count the cards contributing to the numbers $N_r{}'$ and $N_r{}''$ according as X (instantaneous value) or 1 (average hourly values) appeared in column 79. On the third reading the first 12 magnetic values were read into the 418 counters with appropriate sign, the 13th value was read into the 605 (FS4)*, a 1 digit was also read into the 605 (FS1) if there was an X in 79 or into another 605 unit (FS2) if there was a 1 in 79, and 0.1 K was read into the remaining storage unit (MQ). During 605 calculate time ** these numbers in factor storage were added to the previous sums in the general storage units and multiplier quotient and the results read into the latter. Upon reading a summary card (X in 77) the major program star was impulsed. On program step 1 and the following 605 calculate time the sum of the constants K were added to the 13 sums and the results in the 418 were balance tested. On the second program step and following 605 calculate time the last position of each hourly value was rounded and the numbers in FS1 and FS2 were added to give the total number of cards. The third program step was used to impulse summary punching and to read out and print the totals. The summary punched cards contained the 13 sums (the 13th value was zero for sets B_1) of up to five digits (columns 5-69), the number of X's in 79 (columns 70-72), the number of 1's in 79 (columns 73-76), and the total number of cards (columns 77-80). The same information was printed plus numbers obtained from the first card of each group indicating the parameter that was constant for that group.

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* FS, GS, and MQ designate respectively the factor storage, general storage and multiplier quotient units in the 605.

** The 605 electronic calculation cycle takes place the end of each 418 cycle.

The sorting for each run was first made on the solar or magnetic activity numbers and then on the other parameters. The summary cards were placed behind each pack by hand for the solar runs but were punched with appropriate group numbers and sorted with the detail cards for the lunar runs. All of the sorting into the larger groups was checked by needling.

After each run the summary cards were numbered by hand with the index numbers in Table 6. This was necessary as there was no way of automatically numbering each group as it was run. It was also impractical to place a previously indexed set in the 527 as there were frequent stops during the run due to card jams or plugboard testing by other CPC users. After indexing the summary cards, which will be designated sets C_1 and C_2, corresponding to B_1 and B_2, the last ten columns of C_1 and C_2 were compared on a reproducer. This comparison was generally sufficient to find sorting or summing errors, the latter occurring primarily due to card jams in the 418 feed hopper. Card jams were quite frequent during the hot, humid weather in New York during the summer of 1953 so that the operation took considerably longer than the basic machine time.

Even after extensive testing it was found that certain combinations of cards would produce erroneous results, but their frequency of occurrence was such that it was not thought worthwhile to correct them. One of these was the fact that if the 13th sum was negative when totalled, the nine's complement was punched and printed instead of the absolute value with a minus sign. As only one negative value was found, and this not in the 13th value, this condition was left uncorrected. The other peculiarity was that if the first card in a group has a four-digit number in both the 13th position and in one or more of the first 12 positions, then the constant in column 63 (thousands position of K) is multiplied by three before being added to the 13th value of the last card of the preceding group. Because of the rarity of such an event, and the difficulty of tracing its origin, it was also uncorrected. Errors of addition of numbers are to be checked by comparing the sums of the various groups. However, as a group of test cards was used before each run, it is thought that no gross errors could have occurred.

After the summary cards were checked and compared a set of index numbers were reproduced from a master sequence set into columns 1-4. These were then run through an interpreter which printed the index number, the first six sums and the card counts in the last ten columns.

The 418 was then wired to add the first 12 group sums and print the total on encountering a summary card (X in column 80). Due to lack of time the 13th value and card counts were not wired as they would have involved the complication of passing numbers to and from the 605. The summary cards were then added on constant a or R class numbers, whichever happened to be the major divisor for that group. The a-sn groups were sorted manually on sn and summed on each of these groups. These printed totals will be used to check the results as well as to illustrate the general vairations.

8. Machine Time

Table 8 gives the breakdown of machine time both by operations performed and by installations used. Except for the keypunch and verifier these are calculated on the basis of the number of card cycles and the rates of the particular machines. The actual time required for these operations, including plugboard wiring and card handling, was of course, considerably greater.

TABLE 8

Operation	Type of Machine	Machine Time Hou
1. Punching and Direct verification	077 Keypunch	1530 hours
	Verifier	220 "
2. Verification by summing	513 Reproducer	9.1 hours
	077 Collator	3.8 "
	407 Accounting Machine	42.5 "
3. Conversion of 52 data	513-519 Reproducer	1.3 hours
	077 Collator	.6 "
	602 - A	11.0 "
	Sorter	.3 "
4. Preliminary operations	Sorter	8.2 hours
	Collator	7.6 "
	405 Accounting Machine	8.9 "
	513 & 519 Reproducers	42.7 "
5. Summations	Sorter	11.3 hours
	CPC	89.3 "
	Interpreter	3.3 "

Total Machine Time

1.	College, Alaska - punching and verifying		1750 hours
2.	Anchorage, Alaska - further verification		55 hours
3.	Watson Scientific Computing Laboratory		
	Sorters	20 hours	
	Collators	9 "	
	405 Accounting Machine	9 "	
	513 and 519 Reproducers	43 "	
	Interpreter	3 "	
	CPC II	90 "	
	602 - A	11 "	
		185 hours	185 hours
		TOTAL	1990 hours

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